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Noise Behaviour of Zener Diodes

While assembling a broad-band amplifier for a magnetic active aerial, the author observed a number of remarkable effects when he used Zener diodes for phase coupling and potential displacement. This led him to study the phenomenon of noise in Zener diodes in greater detail.

1. INTRODUCTION

Noise from power supplies has already been discussed frequently in "VHF Communications" in relation to low-noise oscillator circuits. Previous articles have been more concerned with practical aspects, namely the assembly of "cleaner" power supply systems, whereas no attention has been paid to the main cause of the phenomenon - noise in the voltage reference.

As manufacturers do not give information about the noise behaviour of their products, the only alternative was to carry out my own measurements. No attempt was made to investigate the "flicker noise" at frequencies of a few Hertz, as the measurement technique is not exactly simple. Due to the small quantity of equipment involved and to the fact that testing was limited to three companies' products (ITT, Motorola and Philips), my results are certainly not a hundred per cent representative, but comparison measurements on a few ancient Z diodes from the sixties and seventies showed that the trend is correct.

2. THE PHYSICS OF ZENER DIODES

Two distinct physical mechanisms are concealed behind the Zener diode component:

2.1. The Zener Effect

In Zener diodes with relatively low breakthrough voltage levels below about 6V, the Zener effect is the triggering factor (the electrons "tunnel through"

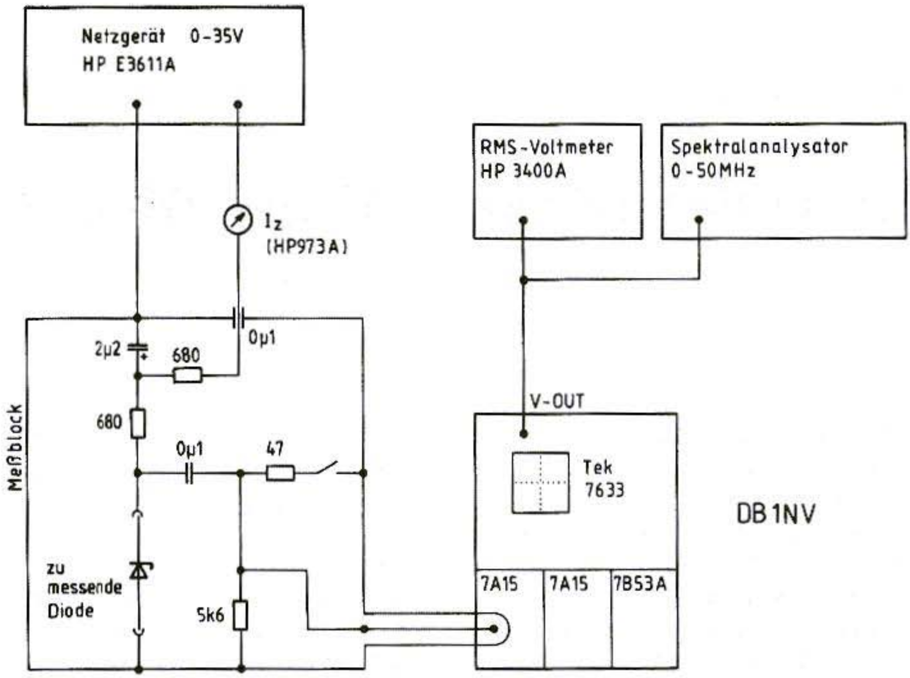

Fig.1: Measuring Rig for Measuring Zener Diode Noise
Netzgerät **= Power supply,** ***Spectralanalysator*** **= Spectrum analyser,**
Meßblock **= Measuring block,** ***Zu messende Diode*** **= Diode to be measured**

the barrier layer, as in the tunnel diode). These Zener diodes display a negative Zener voltage temperature cycle, and the bend in the barrier characteristic is not particularly sharp. To put it another way, the differential internal resistance (i.e. the reciprocal value of the characteristic gradient) of the Zener diode is rather high. For a current of 1mA and a Zener voltage of 2.4V - 5.6V, it can lie between 100Ω and 400Ω. Values of around 100Ω are typical for a Zener current of 5mA.

2.2. The Avalanche Effect

Zener diodes with breakthrough voltages exceeding 6V use the avalanche effect, or avalanche breakdown. Here electrons originating spontaneously in the barrier layer are so strongly accelerated through the barrier voltage which is applied that they can knock electrons out of other atoms, which are now accelerated in their turn. The result is an electron avalanche, which we observe as current (I hope the physicists among our readers will forgive the simplified representation without band models). The avalanche breakdown has a positive temperature coefficient and the differential internal resistance is considerably lower. For a current of 1mA and for Zener voltages of 6.8V - 15V, 30Ω to 200Ω is typical. For a current of 5mA, the current is only 5 - 20Ω.

Zener diodes with a breakthrough voltage of between 5 and 6V are distinguished by two features

Firstly, the differential internal resistance reaches its absolute minimum here, and secondly the Zener and avalanche effects are superimposed. Since the two effects have opposing temperature cycles, the resulting temperature coefficient is almost zero. For this reason, reference diodes with high stability and a low temperature cycle are usually structured for around 6V.

With regard to the noise behaviour of Zener diodes, most instruction manuals will tell you that the noise diminishes as the Zener current increases.

While creating a broad-band amplifier, the author came across the following remarkable facts:

1. Noise values differing by powers of ten can be obtained even from diodes from the same source

Measurement Bandwith 300 Hz - 15 MHz

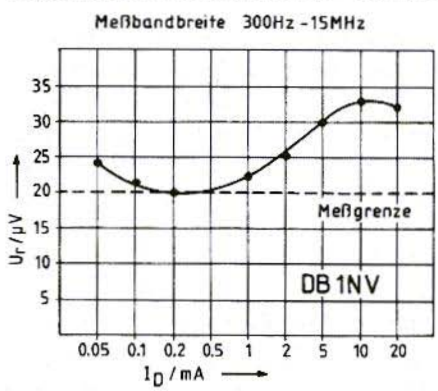

Fig.2: Noise Behaviour of "real" Zener Diode BZX83C4V3
***Meßgrenze* =Measuring limit**

2. The avalanche and Zener effects display completely different types of noise behaviour
3. Chaotic relationships can often be observed between diode currents and noise
4. The spectrum distribution of the noise varies with the specimen diode and the current

3. A MEASUREMENT RIG TO DETERMINE THE NOISE PROPERTIES

To measure the noise of a Zener diode, you need a well-screened and decoupled measurement rig, as otherwise local medium-wave and short-wave transmitters can be measured instead of the diode noise.

Fig.1 shows the rig set up. A closable tinplate housing contains the Zener diode. The bias voltage is fed into the screening housing through a feedthrough capacitor and an RC module, against low-frequency noise. The bias voltage is provided by a low-noise power pack (HP E3611A). The diode current is measured using a battery-driven multimeter (HP 973A), which avoids parasitic couplings such as often arise in mains-operated multimeters.

The noise voltage is tapped through a high-pass at 300 Hz, and is fed into an oscilloscope with a high-sensitivity vertical amplifier (Tektronix 7633 with

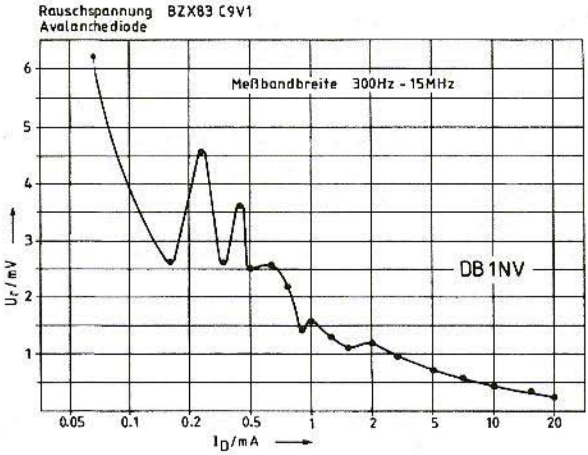

Fig.3: Noise Voltage of Avalanche Diode BXZ83C9V

***Rauschspannung* = Noise voltage, *Meßbandbreite* = Measuring band width**

7A15 vertical plug-in unit). The deflection factor lies at 500µV/cm.

The signal, pre-amplified by a factor of 50, is tapped at the vertical output of the oscilloscope and is fed in parallel into a broad-band effective value voltmeter (HP 3400A) and a spectrum analyser (built by the author himself). The 3dB band width of the measuring rig lies at 300 - 15 MHz, and the internal amplifier noise relating to the test object at 20µVeff.

There is an additional 50Ω load resistor in the screening housing which can be connected up, which makes it possible to specify the internal resistance of the "Zener diode" noise voltage source.

Even the first experiments showed that the internal noise resistance of the Zener diodes was only a few Ohms. This confirmed a fact well-known from experience, that the direct parallel wiring up of a capacitor alters the noise of a Zener diode only a little. The source impedance is just too low!

4. THE NOISE BEHAVIOUR

The group of "real" Zener diodes (BZX83C4V3, BZX83C5V6, BZX79C5V6, ZPD4.7, ZF5.6) with Zener voltages of 5.6V and below, all displayed noise voltages which increased with the diode current. For some specimens, saturation occurred at currents exceeding 10mA, or the noise even decreased again.

The readings for the ancient specimen ZF5.6 were no different from those for newer types. For current levels varying between 100µA and 1mA, the noise voltages were below 20µV, i.e. within the internal noise limits of the measuring rig. For current levels of between 5 and 20mA, the maximum noise voltage which could be measured was app. 100µV.. The spectrum distribution was approximately uniform (white noise). A shallow noise hump could frequently be observed at 5 to 10 MHz, which migrated to higher frequencies as the diode current increased.

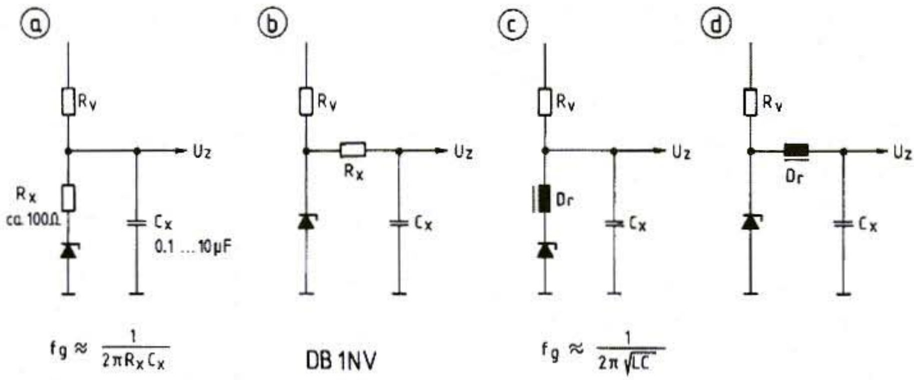

Fig.4: Filter Circuits for Zener Diodes

For the avalanche diodes (BZX83C7V5, BZX83C9V1, BZX83C27, ZPD7.5, ZPD10), the textbook cycle for noise voltage plotted against the diode current ensued. At low current levels of 100µA, noise voltages could be measured of 2 - 4mV, which fell back to values of between 150µV and 1mV for a current of 10mA. But the decrease is not uniform. Instead, it displays numerous minimum and maximum values in the current range below 2mA.

The levels and positions of the maximum values are subject to strong scattering effects which vary from one specimen to another. Perhaps a semiconductor specialist among our readers could find an explanation for this.

The behaviour of two transient protective diodes, type 1.5KE6.8, was particularly remarkable. Here, the noise generation set in abruptly at current levels of between 1.2 and 2.4mA!

Figs.2 and 3 show examples of the noise voltage, plotted against the current, for a "real" Zener diode (BZX83C4V3) and an avalanche diode (BZX83C9V1).

Sample LED's of various colours from various manufacturers displayed no measurable noise when measured!

5. ADVICE PROPOSALS FOR CIRCUIT DEVELOPERS

When using Zener diodes in low-noise voltage control circuits, or for coupling, operation point setting and potential displacement in amplifiers, the basic rule is as follows - Zener diodes are a low-Ohmic source of noise voltages (internal resistance < 50Ω), with a spectrum which extends up into the megaHertz range.

The noise is not specified in the manufacturers' data sheets, and is subject to strong scattering effects which vary from one specimen to another, with associated chaotic current dependencies.

The following rules can be derived from the measurement results:

1. If the Zener diode can be operated at high levels of current (exceeding 10mA), then the differences between Zener and avalanche diodes are blurred, although the "real" Zener diodes have a tendency to generate less noise.

2. At low current levels below 1mA, the noise from avalanche diodes increases rapidly. Minimum and maximum values arise, which can lead to the curious case in which increasing the current may even increase the noise.

3. Real Zener diodes (U ≤ 5.6V) generate only a little noise, even at low current levels below 1mA, but they have a higher internal resistance, leading to poorer stabilisation properties. They are thus better suited to low-noise voltage controllers, for battery-operated equipment, or for coupling and operation point setting in amplifiers.

   From the point of view of noise behaviour, it can be worth while to connect up several low-voltage Zener diodes in series, instead of using one avalanche diode. The noise from one Zener diode for operation point setting can be amplified directly in a broad-band amplifier, or can modulate the output frequency in an oscillator.

4. Extremely low voltages below app. 3V can more expediently be stabilised using light-emitting diodes operated in the conducting direction. The temperature coefficient is considerably lower than for silicon diodes in a series circuit.

The following table compares typical temperature coefficients.

Diode type	Temperature coeff. in mV/°C
1N4148	-2mV/°C or -0.28%/°C
IR LED	-1.6mV/°C or -0.1%/°C
Red LED	-1.4mV/°C or -0.08%/°C
3V Zener	-2.7mV/°C or -0.09%/°C
5.6V Zener	±0mV/°C
10V Zener	+6mV/°C or +0.06%/°C
20V Zener	+16mV/°C or +0.08%/°C

There are "Zener diodes" for low voltages, such as the BZV86 range from Philips, which consist of just 2 or 4 silicon diodes wired up in series, and which are operated in the conducting direction. Their temperature cycle corresponds to that of normal silicon diodes!

5. Since the noise resistance of the "Zener diode" noise sources lies at only a few Ohms, connecting a capacitor up in parallel to reduce the noise is rather pointless. Large capacitors would be required, and moreover the effective series resistance of the capacitor is too high to short-circuit the noise voltage.

   Assistance is provided by an LC or RC filter between the Zener diode and the consumer, which naturally increases the static or dynamic internal resistance of the stabilisation circuit. Fig.4 shows some examples.

6. SUMMARY

Zener diodes with a breakthrough voltage exceeding 6.8V are not suitable for generating low-noise operating voltages unless careful after-filtration is provided for and the diode can be operated at high levels of current (app. 10mA).

Zener diodes with a breakthrough voltage below 6.8V (Zener diodes in the narrower sense) generate at least 20dB less noise output, and can thus be operated even at low levels of Zener current (below 100μA), since the noise output generated is largely independent of the current. This is of particular interest in relation to battery-operated equipment.

The noise output is subject to strong scattering effects which vary from one specimen to another, and displays chaotic oscillations in the operating current, particularly with avalanche diodes (> 6.8V).

Since the noise spectrum is approximately "white" up to at least 50 MHz, these effects can be used to construct simple noise generators - e.g. for the well-known aerial noise bridges.

One alternative remains to diodes operated in the conducting direction for the stabilisation of very low voltages - the use of LED's. They are less temperature-dependent, and they generate no measurable noise.